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# Product specifications and business practices as food loss drivers – A case study of a retailer's upstream fruit and vegetable supply chains

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ABSTRACT

The issue of food loss and waste is vital for minimising resource consumption and $CO_2$ emissions. In particular, reducing fruit and vegetable loss and waste would contribute to keeping the food system within planetary boundaries. At the same time, food loss occurrence from primary production up to the store is underestimated and receives relatively little scientific and political attention. This case study focuses on specific food loss drivers, namely retailers' quality standards and business practices. It provides answers to the questions of how and to which extent standards and practices of the large German retailing company Lidl induce food loss in the upstream supply chain of 12 fruit and vegetable crops. To this end, we conducted qualitative interviews with supply chain actors, followed by an online survey with Lidl suppliers from Germany, Italy, and Spain. Our results indicate that, on average, 15% of the total production in the field ready for harvest does not comply with the retailer's product requirements. While most of it is marketed elsewhere, around 6% of the total production become food loss (non-harvest, animal feed, disposal, non-food items) as a direct consequence of these requirements. Retailer-specific pesticide residue limits and calibre (mass and size) followed by shape and sorting requirements are the most relevant product standards inducing food loss. The retailer's business practices such as insufficiently synchronised advertisement campaigns, return deliveries, short-notice quantity call-offs and improvable quantity planning and ordering processes add onto this. Many suppliers do not view the retailer-specific product requirements and practices as drivers of food loss and report low shares of substandard products. However, methodological constraints must be considered, such as potential selection biases, underreporting in questionnaire surveys and the study focus on suppliers rather than upstream primary producers. From this study, concrete recommendations can be drawn for retailers to adjust and handle their product requirements and business practices in order to prevent food loss at upstream supply chain stages.

## 1. Introduction

Reducing food loss and waste (FLW) levels can make a significant contribution to the conservation of our natural resources. The United Nations (UN) with Sustainable Development Goal (SDG) 12.3, the Farm-to-Fork Strategy (European Commission, 2020a) as well as the European Circular Economy Action Plan (European Commission, 2020b) prioritise FLW as areas for action towards the goal of obtaining not only a more sustainable food system but also a less resource intensive economic system overall.

Despite this topicality, large data gaps and variations with respect to FLW levels prevail as data generation across all scales and stages remains a challenging task (Parfitt et al., 2021). FAO (2020) and UNEP (2021) present figures on global FLW levels within their Food Loss and Food Waste Indices. These anticipate that 14% of all food becomes food loss at pre-retail stages and 17% gets wasted between retail and consumption. For Europe, it is estimated that food loss in primary production corresponds to about 18 kg per person per year, including edible and inedible parts (Stenmarck et al., 2016).

One of the difficulties in generating and providing reliable data arises from inconsistencies in defining FLW. The FAO (2019) distinguishes 'food loss' from 'food waste', where food loss accumulates between primary production and retail and food waste arises on retail and consumption stages. In the European Union, only the term 'food waste' from production up to and including consumption stages is legally defined, while the term 'food loss' is not defined at all by the European Commission (European Commission, 2019). Loss that occurs before or during the harvesting process, as well as food that is redirected to animal feed or

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towards the non-food industry is often not considered food loss or waste (European Commission, 2019; FAO, 2019). Some authors however argue that pre-harvest loss and fractions utilised as non-food should be integrated in the definition or at least taken into account in scientific evaluations (Baker et al., 2019; Hartikainen et al., 2018; Parfitt et al., 2021; Soma et al., 2021; Stenmarck et al., 2016). Leaving out this part of production results in underestimating the actual magnitude of loss, the associated resource use and the underlying drivers (Cattaneo et al., 2020; Delgado et al., 2021). This study focusses on the supply chain upstream the retailing stage and uses the term ‘food loss’, thereby also considering harvest and pre-harvest stages. By analysing fruit and vegetable loss on pre-retail stages, the paper addresses two subject areas that are relevant but under-represented in current research. First, fruit and vegetables are among the product groups with high loss rates (Caldeira et al., 2019; FAO, 2019). Although reducing fruit and vegetable loss and waste would contribute comparatively little to reducing greenhouse gas emissions (WWF, 2021), it would indeed help keep the food system within planetary boundaries of nitrogen and phosphorous application and blue water use (Springmann et al., 2018). Second, food loss at pre-retail stages in industrialised countries is an important issue as its magnitude, especially for fruit and vegetables, is underestimated (Parfitt et al., 2021; WWF, 2021). High- and middle-income countries in Europe, North America and Asia contribute 58% of loss at the harvesting level globally, despite inhabiting a smaller share of the global population. Worldwide, farm stage and food loss prior to retail adds up to 20–25% of total production (WWF, 2021).

There is a growing body of literature dealing with food loss in the retail sector, such as store operations (Teller et al., 2018), in-store food waste drivers (Cicatiello et al., 2020; Moraes et al., 2020) and extending the shelf-life and freshness of products in supermarkets (Broekmeulen and van Donselaar, 2019). Fewer studies have focused on food loss at the supplier-retailer interface by analysing specific trading practices (Brancoli et al., 2019) or by examining the links between resilience and food loss and waste at this interface (Moraes et al., 2019).

This paper addresses this research gap by assessing food loss drivers specific to the production-retail interface: the product specifications and business practices that retailing companies impose on the upstream supply chain. Product specifications or quality requirements refer to visual and inherent characteristics of the crop. The EU has, within their trade category regulation, laid out basic criteria for all horticultural products. More specific criteria apply to ten fruit and vegetable crops (European Commission, 2011), representing 75% of the EU trade value (UBA, 2020). The United Nations Economic Commission for Europe (UNECE) has supplemented these with voluntary criteria for most of the remaining crops, on the basis of which products may be and in practice are grouped into commercial categories (UNECE, 2020). Various authors have shown that company-specific product specifications of retailers go beyond legal requirements, thus resulting in products being sorted out and becoming food loss at early stages of the supply chain (Beausang et al., 2017; de Hooge et al., 2018; Herzberg et al., 2022; Johnson et al., 2019; Ludwig-Ohm et al., 2019; Meyer et al., 2017; Porter et al., 2018; Richards and Hamilton, 2020; UBA, 2020). Reasons for retailers placing specific demands on products include the need to introduce product differentiation (Gereffi et al., 2005), price-discrimination strategies (Richards and Hamilton, 2020), cost-efficient transportation of uniform products (UBA, 2020) and above all the fulfilment of consumers’ demands for appealing products (Aschemann-Witzel et al., 2017; de Hooge et al., 2017; Hartmann et al., 2021). However, there is an ongoing ‘chicken-and-egg’-debate as to whether consumers impose these so-called product requirements/specifications or quality standards through their demand in the market or whether supermarkets have educated consumers towards these expectations by competing with each other to offer the most appealing assortment (UBA, 2020).

Johnson et al. (2018a) have shown that 42% of the crop volume that is eventually marketed is left in the field due to poor quality (edible as well as inedible) in a case study for North Carolina (USA). Porter et al. (2018) conducted an estimation of loss resulting from non-compliance with visual product requirements for fruit and vegetables in the European Economic Area based on literature and Eurostat-data. They conclude that these losses vary noticeably between 4% and 37% with a mean value of 14%. Conducting direct measurement on the field, Fernandez-Zamudio et al. (2020) calculated that on average, 11.4% of all the persimmon fruit that was potentially suitable for human consumption was directly left in fields due to different flaws.

Closely related to the setting of retailers’ product specifications are their business practices applied in fruit and vegetable sourcing. These include the ordering process, communication within the chain, planning of advertisement campaigns, contractual terms and conditions and the handling and passing on of the above mentioned product specifications. Rakesh and Belavina (2020), Eriksson et al. (2017) and Herzberg et al. (2022) indicate that the configuration of such practices can influence food loss levels on earlier stages of fruit and vegetable supply chains.

To date, there is no information on which specific product requirements and practices lead to food loss in which crops, nor on the magnitude of loss induced by specific requirements and practices. It is also still unclear where exactly this loss occurs and what happens to products that do not meet retailers’ specific requirements. Therefore, the study pursues the following objectives:

1. To find out how the retailer’s product specifications for fruit and vegetables are applied and if they lead to food loss in the upstream supply chain.
2. To find out how business practices, combined with product specifications, work and if they affect food loss in the upstream supply chain.
3. To quantify the proportion of suboptimal fruit and vegetables in the retailer’s supply chain and to quantify the fractions that become food loss and those that are marketed alternatively.
4. To identify crops, product specifications and supplier groups that are most likely to fail to meet the retailer’s standards.

To answer these questions, we conducted a study in cooperation with the German retailing company Lidl. We involved the retailer’s upstream supply chain actors in Germany, Italy and Spain to receive insights into food loss induced by the Lidl standards. The main part of the study is a quantitative questionnaire with suppliers, supplemented by preceding expert interviews.

## 2. Data and methods

The study applies a mixed methods approach in the frame of a case study with the Lidl Stiftung international. Its corporate social responsibility (CSR) department approached the Thünen Institute in 2020 and expressed an interest in a scientific evaluation of food loss in their fruit and vegetable supply chain, triggered by their own product specifications and related business practices. The authors agreed to collaborate in order to contribute on this scientifically highly relevant topic. The Thünen Institute proposed a study design, while Lidl CSR provided relevant information sources and respondents for the implementation of the qualitative and quantitative survey.

### 2.1. Scope/focus of the study

The present study considers the Lidl supply chains from Germany, Italy and Spain, its most relevant fruit and vegetable sourcing countries in Europe. Fig. 1 shows the focus of the study indicated in green (suppliers and agencies) as well as the partly included dark grey parts (upstream producers, distribution centres). The remaining parts of the food supply chain (stores, consumers) were not considered within this study. We developed a twofold design by conducting preliminary expert interviews with relevant actors in fruit and vegetable sourcing of Lidl prior

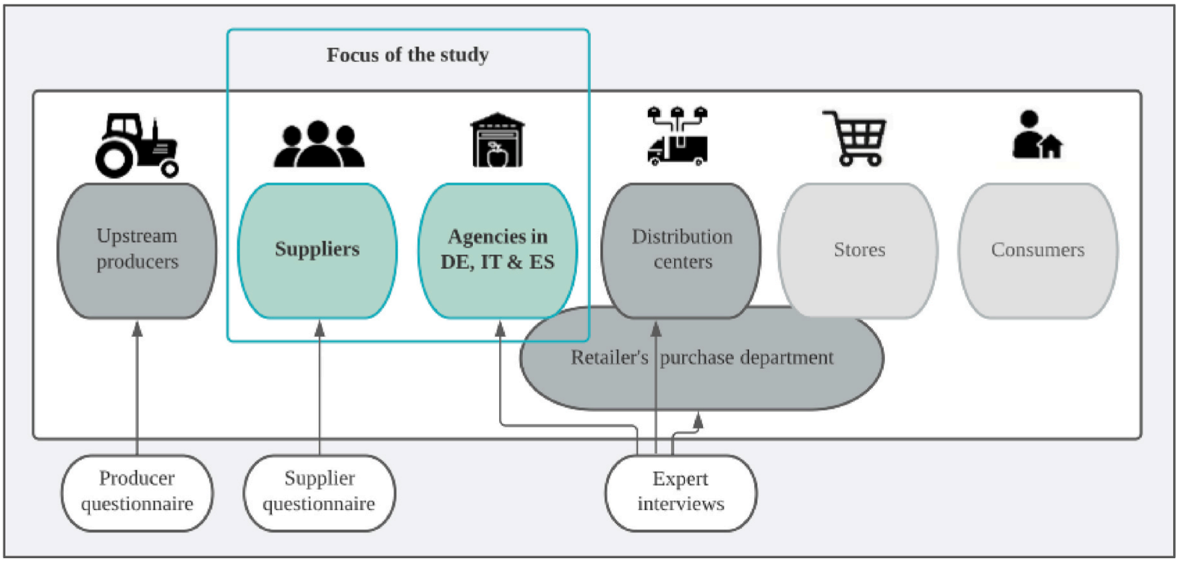


**Fig. 1.** Supply chain actors covered and methodologies applied in the study; suppliers (producers, producer organisations and private traders/brokers) and agencies (interface between suppliers and Lidl responsible for logistics, commissioning, packaging and quality control) are the core of the study (in green); upstream producers results (dark grey) excluded from this paper due to low response rate; distribution centres and Lidl purchase (dark grey) included in qualitative survey only. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

to the store, followed by a quantitative online survey with suppliers and producers within these value chains (Fig. 1). We included the cooperating distribution centres, agencies, suppliers and upstream producers of Lidl in our study. The distribution centres are responsible for commissioning and final quality control just before the stores. Agencies serve as an interface between the supply side and the retailer by taking responsibility for the logistics, commissioning, packaging and quality as well as pesticide residue limit control for Lidl within their respective country. The agencies, proposed to participate in the study by Lidl, are among the retailer's largest agencies and represent a substantial share of its trade flow within Europe. It therefore makes sense to include them as representatives of this stage of the supply chain.

### 2.2. Preceding expert interviews

We conducted five expert interviews between December 2021 and February 2022 with

- one purchaser of fruit and vegetables of Lidl
- one representative of a fruit and vegetable distribution centre in Germany
- as well as with the managers of all three so called fruit and vegetable agencies, responsible for German fruit and vegetable sourcing in Germany, Spain and Italy, respectively.

The experts were selected based on the fact that fruit and vegetable purchase, logistics centres and agencies represent the mainstays and points-of-decision concerning the supply chain between suppliers and stores. While the purchasers are employed by Lidl itself, the representatives of the distribution centres and agencies are employees of independent companies, which, however, maintain long-term business relationships with Lidl. The interview partners of all three institutions were selected and acquainted to us by our contact persons from Lidl CSR. The interviews primarily aimed at gaining an understanding of the functioning of supply chains, trade flows, the institutions' roles within the chain as well as of the perceptions of product specifications and food loss. The interview guideline was subdivided into four main thematic blocks, consisting of one to five questions each (Supplementary material 1):

Thematic block 1: Company/institution, position within and functioning of supply chain
Thematic block 2: Trade flows, ordering processes and quantity planning
Thematic block 3: Product specifications and the process of quality management
Thematic block 4: Food loss, drivers and loss points and return deliveries

In all interviews, the interviewee, two authors of this paper as well as representatives of the purchase department and CSR divisions of Lidl were present. Interviews were not recorded but notes were taken and evaluated afterwards.

### 2.3. Online survey with suppliers

We implemented the online questionnaire within the LimeSurvey setup of the Thünen Institute. Suppliers and upstream primary producers of twelve crops were selected to answer the online questionnaire. We decided to base the survey on suppliers and producers because food loss due to quality criteria is likely to occur during production and early in the supply chain (Beausang et al., 2017; Johnson et al., 2019; Soma et al., 2021). The selection of crops was based on discussions with the agencies, volume traded in the EU and by Lidl, loss rates drawn from the literature and the need to apply EU trade category regulation. We define suppliers as those entities maintaining direct trade relations with the agencies. There are three types of suppliers within the supply chains evaluated: firstly, large farmer suppliers who supply directly to the agencies; secondly, producer associations; and thirdly, private traders or brokers. In contrast to suppliers, upstream primary producers do not have direct trade relations with the agencies. Suppliers and upstream primary producers received distinct versions of the questionnaire. However, due to the limited scope and an unsatisfactory response rate among upstream primary producers, only the results of the supplier questionnaire are presented in this paper. (Supplementary material 2). It addresses the following key points in the form of open-ended, multiple-choice and Likert-scale questions:

1. Quantities and trading partners

2. Product specifications: existence, types and manner of passing on specifications
3. Non-compliance with product specifications: shares and channels of substandard produce
4. Food loss drivers with a focus on product specifications and business practices
5. Crop specific food loss drivers: comparison of Lidl standards with EU and UNECE standards
6. Options for action: suppliers' options, retailer's options, policy options
7. Supplier characteristics: size, fruit and vegetable volumes produced or traded, organisational structure, crop management

We discussed and improved the questionnaires' applicability and comprehensibility with all three agencies in several feedback loops. Additionally, we conducted pre-tests with fruit and vegetable producers, practitioners and scientists in the field. A professional service provider translated the German questionnaire into Spanish and Italian.

Agencies were asked to use their established communications infrastructure (mailing lists, information systems) to recruit their suppliers for the survey. Agencies in Germany and Spain sent the questionnaire link to all suppliers of the selected crops. The agency in Italy preferred to omit suppliers delivering negligible quantities on an irregular basis to Lidl. They argued that very infrequent suppliers would not be able to answer the specific questions of the survey anyway. The total number of suppliers in all three countries is 717 according to the information we received from Lidl (Supplementary material 14). The questionnaires were available online from April 20th to July 14th, 2022.

### 2.4. Data analysis

Expert interviews were conducted in order to gain insights into value chain functioning that serve as a basis for the quantitative part of the study. Therefore, and since it was not possible to record and transcribe the interviews, we refrained from performing a structuring qualitative content analysis.

The processing of questionnaire data can be divided into data cleansing, descriptive analysis and inductive statistics. Due to the extensiveness of the questionnaire, we included partially completed questionnaires, provided they had got past the initial questions concerning supplier type, crop and volumes traded. Of 430 suppliers who had started filling in the questionnaire, 205 were sorted out initially. Furthermore, ten duplicates were sorted out. In the course of data cleansing, we further erased implausibly high indications of produced and traded quantities in consultation with the respective agency, while keeping the remaining answers provided by these four cases within the data set. The total number of questionnaires included in the analysis was 215, resulting in an average response rate of 30%. However, the rather long and cognitively demanding questionnaire led to suppliers dropping out of the survey along the way, leading to significantly lower response rates for some items (see section 3).

We carried out descriptive analyses of questionnaire data by use of IBM SPSS 23 and Microsoft Excel 2019. We calculated response rates based on indications of the company concerning the number of suppliers in the population. We then depicted relevant characteristics of these respondents per supplier type, crop and country. Respondents' perception of the Lidl product requirements and business practices in general and as a driver of food loss were mainly depicted graphically (e.g. using diverging bar charts) and by use of statistical parameters. We moreover calculated mean shares of products not reaching the product requirements as well as shares of this produce going to alternative marketing channels. Here, we used respondents' total production and traded volume as reference values.

We hypothesised differences and correlations of

A) indicated shares of products not fulfilling requirements and
B) indicated shares of products becoming food loss (disposed, used as animal feed, non-food products or left unharvested),

between/with

a) the country/agency (Germany, Italy, Spain),
b) the supplier type (farmer supplier, broker, producer association),
c) the selected crop,
d) whether or not there are other buyers besides the retailer's agencies,
e) whether or not the supplier produces/trades (among others) organic produce,
f) the total produced or traded volumes of fruit and vegetables,
g) the number of buyers apart from this retailer
h) the duration of the business relationship between the supplier and the respective agency.

In preparation for hypothesis tests we created boxplots (Supplementary materials 3 to 12) to visualise potential differences between groups for the categorical variables. Descriptive statistics of all variables can be found in supplementary material 14. We performed hypothesis testing in RStudio (2022.02.2). For both target variables (A and B) and all categorical variables (a-e) we applied non-parametric Kruskal-Wallis tests in case of more than two groups (a-c) and Mann–Whitney U tests in case of only two groups (d-e). For continuous and discrete variables (f-h) we calculated pearson's correlation coefficient. In the event of significant differences between groups as indicated by Kruskal-Wallis test, we used the Dunn-Bonferroni post-hoc test to detect those groups that differ significantly from each other.

In order to assess the influence of certain predictors and control for interactions between them, we further set up two distinct regression models describing the target variables A and B. We employed a quantile regression approach using the variables a-c and e-h (list above) as regressors. Variable 'd' is omitted as variable 'g' (the number of buyers apart from this retailer) already describes the case where the supplier has several outlets other than Lidl. The models enable describing specific quantiles of the target variable separately and limit the effect of outliers (Koenker, 2009). If the relationship between variables is likely to perform differently at different quantiles, the approach is preferred over ordinary least squares (OLS) regression in practice, as it allows coefficients to vary with quantiles (Opoku and Aluko, 2021; Wang et al., 2019). The models for dependent variables A and B, respectively, are set out as described in formula below.

$$Q_\tau (y_i) = x_i \beta (\tau) + \varepsilon_i$$

where $y_i$ represents the dependent variables A and B, respectively,

$Q\tau$ indicates the $\tau$th quantile of the dependent variable,
$xi$ denotes the vector of all the independent variables (variables a–c and e–h),
$\beta$ represents the regression parameter to be estimated
$\tau$ denotes the quantile, in our case 0.25, 0.5 and 0.75 and
$\varepsilon i$ represents the error term.

## 3. Results

In the following, we present key findings of the expert interviews (Section 3.1). In Sections 3.2 to 3.6 we illustrate the questionnaire findings, divided into the respondents' characteristics, product requirements and food loss, business practices and food loss, marketing channels and factors influencing suboptimal produce shares.

### 3.1. Functioning of the supply chain and product specifications according to the expert interviews

The interviewees depicted the supply chain functioning related to their perceptions of food loss and quality standards. Despite noticeable organisational differences between each other, the three agencies supply almost exclusively Lidl and source both domestically and from abroad. Thereby, the goods become the property of Lidl only when they are accepted at the distribution centre in Germany.

Product specifications concerning appearance, packaging and pesticide residue limits are passed on from the retailer to the agencies in the form of a certain specification sheet. Agencies perceive this document as a guideline. The parent purchase department, which is responsible for issuing them, sees them as a flexible means of documenting product characteristics that may be adapted on a weekly basis. According to the purchase department, the only requirements specific to Lidl are to comply with either UNECE standard class I or trade regulation class I as well as with specific pesticide residue limits and corporate design of packaging.

The interviewees draw a diverse picture regarding food loss caused by product requirements. However, interviewees agree that almost no loss occurs at the point of the agencies. Return deliveries at agencies and distribution centres exist but most sorting takes place prior to the agency. Interviewees explain that it is decided on a case-by-case basis and depending on the respective loss point what happens to this fraction of produce. It might be 'made available' to suppliers, utilised for biogas production or marketed elsewhere. In these cases, the supplier pays the costs for food loss. There is no explicit restriction in place by Lidl that hinders produce to be marketed alternatively if rejected by the agency or distribution centres. In case of doubt regarding compliance with quality requirements, agencies consult the Lidl purchase department of Lidl that in turn decides on the acceptability of produce. As described by purchasers, they react flexibly if products do not fully align with the expected quality.

### 3.2. Characteristics of suppliers within the questionnaire sample

Response rates range from 11% for cucumbers to 75% for carrots (for further response rates see Supplementary material 13). With 72%, the largest share of respondents is situated in Spain, followed by 20% from Italy and 8% from Germany (Fig. 2). The imbalance within the sample roughly reflects the different sizing of the agencies within the three countries, with Spain having the largest number of suppliers, Italy the second largest and Germany the smallest (Supplementary material 13). With respect to supplier types, most suppliers (103) in the sample are farmers themselves. However, this differs depending on the country. The German agency almost exclusively sources from farmer suppliers and also in Spain, the share of farmers among suppliers with 79 out of 154 is quite high. Similarly, the supplier type varies between crops. Lettuce and mandarins are predominantly sourced from farmer suppliers, while tomatoes, apples and bell peppers are largely supplied by producer associations.

When looking at supplier sizes, indicated by cropping area, produced and traded volumes and number of members or upstream vendors, the variety within the sample becomes apparent. Cropping areas range from less than one to 15,000 ha. Farmers in Germany are the smallest, Spanish farmer suppliers the largest. The average farmer supplier hereby grows 11,000 tons of the chosen crop per year; the average farmer of a producer association grows 34,500 tons. The smallest grower in the sample cultivates 5 tons of apples and the largest 56,000 tons of cucumbers per year. With respect to volumes traded, producer associations trade a mean of 25,100 tons and brokers 8,900 tons. Producer associations in the sample on average comprise of 211 members with a maximum of 1,300 members for Italian apple producer associations. Private brokers in the sample purchase fruit and vegetables from an average of 20 producers.

Both cultivation methods, organic and conventional are represented in the sample. The majority cultivates or trades fruit and vegetables in a conventional manner, while 7% grow/trade exclusively organic products and 26% cultivate or trade both.

Only 17% of the sample suppliy their entire production to the agency that in turn supplies Lidl. The remaining share of the sample supplies an average of 25% of the traded volume to the respective agency. Regarding further marketing channels, export, other retailers and wholesale make up the largest shares of volumes traded by the suppliers.

### 3.3. Product requirements and food loss

The aim of the survey was to find out which requirements lead most to food loss in the Lidl upstream supply chain. Firstly, it seeks to answer the question of whether Lidl sets product requirements at all. Secondly, it contrasts these requirements as drivers of food loss with other drivers and with each other. 98% of respondents report that Lidl demands some kind of company-specific product characteristics. Suppliers indicate that all potential product requirements provided are existent within the supply chain. Among these, requirements concerning pesticide residue limits (PRL) as percentage of legal requirements and as maximum number of substances as well as requirements on calibre are mentioned most frequently (Fig. 3).

The notion whether certain company-specific requirements exist differs between crops. For instance, all participating suppliers of grapes assure the existence of standards of the retailer concerning pesticide residue limits as percentage of legal requirements. On the contrary, none of the cucumber and avocado suppliers indicate to be given

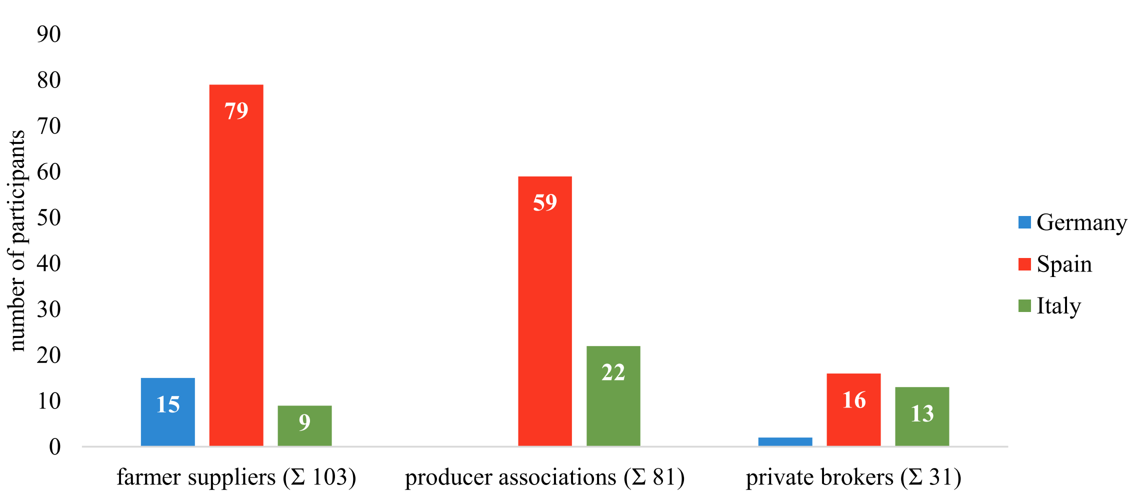


**Fig. 2.** Number of participants in supplier survey by supplier type and country (n = 215).

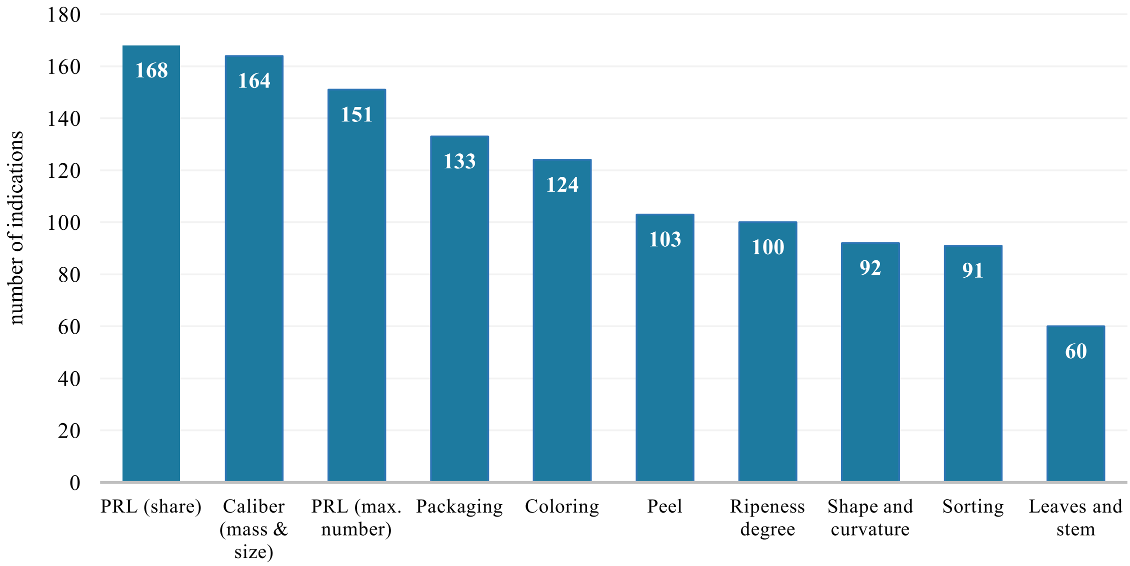


**Fig. 3.** Number of indications regarding which product requirements the retailer imposes on the respective crop, across all crops (multiple choice allowed, n = 178).

requirements on leaves and stem by the retailer.

With respect to overarching food loss drivers from the field to the retailer's warehouse, 21% of suppliers identify product requirements as cause of food loss. Only natural causes, such as weather events and pest infestations, are regarded as food loss driver by more respondents (35%). When looking at specific quality requirements (Fig. 4), many suppliers feel that pesticide residue limits and calibre requirements enhance food loss, followed by shape and curvature, sorting and peel specifications (red bars). All in all, the majority of suppliers does not perceive the requirements specific to Lidl which were available for selection as food loss drivers (green bars).

Whether or not participants regard a certain requirement as inducing food loss seems to depend on the selected crop. Table 1 depicts the averages of the Likert-scaled item on whether a specific quality standard leads to the occurrence of food loss (same items as Fig. 4). Accordingly, product requirements in general appear to have a greater influence on some crops (e.g. mandarins, carrots and tomatoes) than on others (e.g. avocados, cauliflower and cucumbers) and therefore food loss due to requirements are more likely in these crops. Some requirements play a more significant role for loss in certain crops, e.g. calibre and sorting

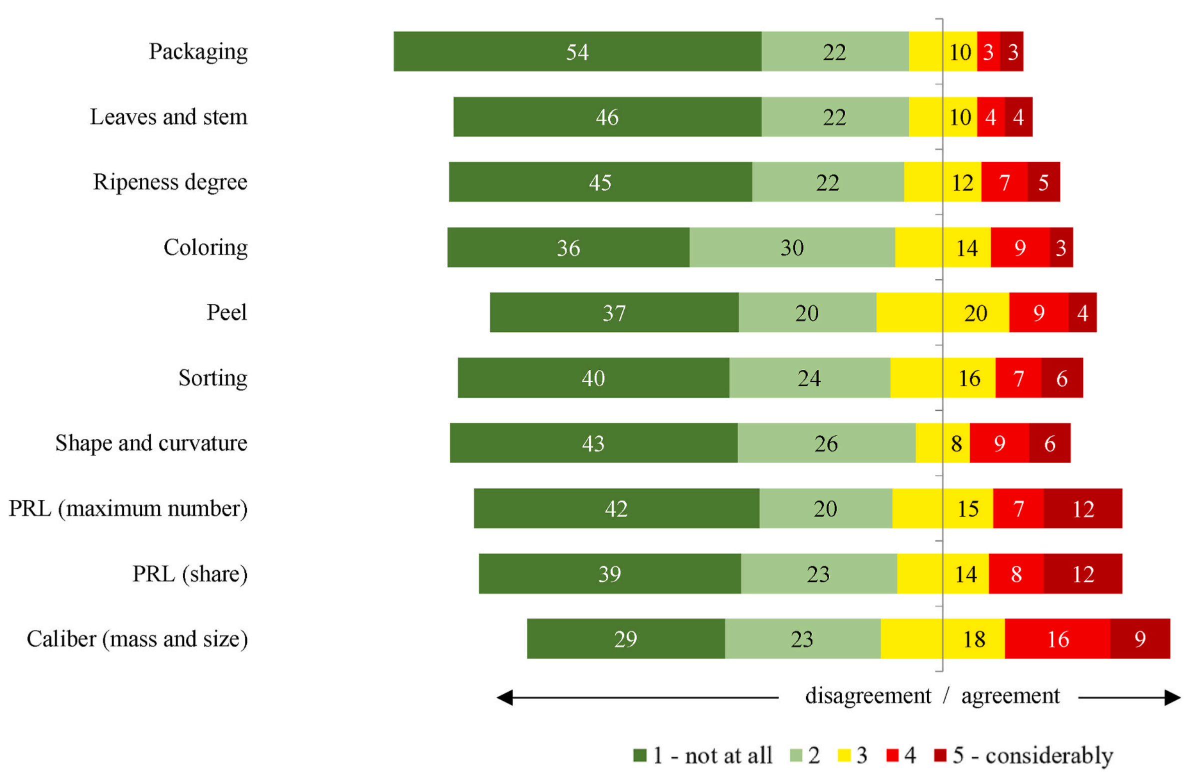


**Fig. 4.** Suppliers' assessment of the extent to which different retailer-specific product requirements lead to food loss on a Likert-scale as percentages of respondents (n = 147 to 148, depending on item; percentages do not sum up to 100% due to omitting NAs).

**Table 1**
Mean values of Likert-items regarding the question of whether certain requirements or practices lead to the food loss in the respective crop.

| | Apples | Avocados | Cauliflower | Iceberg lettuce | Strawberries | Cucumbers | Mandarins | Carrots | Bell peppers | Peaches/ Nectarines | Tomatoes | Grapes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shape and curvature | 1.7 | 1.3 | 1.8 | 1.7 | 1.8 | 1.5 | 2.1 | 2.9 | 2.1 | 1.9 | 2.9 | 1.1 |
| Colouring | 1.9 | 1.5 | 1.9 | 1.6 | 1.8 | 1.8 | 2.6 | 1.9 | 2.3 | 1.5 | 2.9 | 1.6 |
| Calibre (mass and size) | 2.1 | 1.5 | 2.3 | 2.3 | 1.8 | 1.5 | 2.9 | 3.5 | 2.5 | 2.1 | 3.4 | 1.5 |
| Peel | 1.9 | 1.8 | 1.0 | 1.7 | 2.0 | 1.5 | 3.0 | 2.2 | 2.4 | 2.1 | 2.5 | 1.5 |
| Leaves and stem | 1.8 | 1.3 | 1.3 | 2.0 | 1.5 | 1.5 | 2.4 | 1.6 | 2.1 | 1.2 | 2.4 | 1.3 |
| Ripeness degree | 2.0 | 2.0 | 1.0 | 1.4 | 2.2 | 1.5 | 2.4 | 1.3 | 2.1 | 1.3 | 2.7 | 2.1 |
| Pesticide residue limit (share) | 2.3 | 1.3 | 1.4 | 1.9 | 2.3 | 1.8 | 3.4 | 1.9 | 2.6 | 1.5 | 2.3 | 2.4 |
| Pesticide residue limit (max. number) | 2.3 | 1.3 | 1.5 | 1.9 | 2.3 | 1.8 | 3.2 | 2.0 | 2.9 | 1.5 | 2.3 | 2.4 |
| Packaging | 2.3 | 1.5 | 1.0 | 1.6 | 1.5 | 1.5 | 2.0 | 1.2 | 1.9 | 1.3 | 2.2 | 1.5 |
| Sorting | 2.0 | 1.3 | 1.8 | 2.1 | 1.9 | 1.5 | 2.4 | 3.3 | 1.9 | 1.4 | 2.4 | 1.8 |
| Restrictions in alternative marketing channels | 1.7 | 1.3 | 1.9 | 2.0 | 2.1 | 2.0 | 2.8 | 2.5 | 2.3 | 1.4 | 2.4 | 1.6 |
| Short notice of the actual quantities to be delivered | 2.0 | 1.0 | 1.5 | 2.1 | 2.0 | 2.5 | 2.7 | 2.2 | 2.2 | 1.6 | 3.1 | 1.4 |
| Short-term changes in product requirements on the part of the retailer | 1.7 | 1.5 | 1.3 | 1.5 | 2.1 | 2.5 | 2.3 | 2.0 | 1.9 | 1.3 | 2.3 | 1.4 |
| Inconsistencies in calculation between annual planning and called quantities | 2.0 | 1.5 | 2.0 | 2.2 | 2.0 | 2.8 | 2.4 | 2.8 | 1.9 | 1.7 | 3.0 | 1.5 |
| Return of goods as a result of a complaint | 2.0 | 2.0 | 2.0 | 2.1 | 2.7 | 2.8 | 3.1 | 1.9 | 2.5 | 1.7 | 2.4 | 2.4 |
| Promotions insufficiently coordinated with production peaks | 1.7 | 1.3 | 2.8 | 2.5 | 2.1 | 2.8 | 2.9 | 2.9 | 2.7 | 1.8 | 2.9 | 1.8 |
| Insufficient communication between supply chain actors | 1.7 | 1.0 | 1.8 | 1.8 | 1.9 | 2.8 | 2.7 | 2.6 | 2.3 | 1.3 | 2.6 | 1.4 |

Note: on an end-point Likert scale ranging from 1/green (not at all) to 5/orange (considerably): higher mean values (highlighted in orange) indicate higher estimated extent to which requirement/practice induces food loss, number of indications (n) ranges between 5 and 34 depending on crop (row) and item (line)

requirements in carrots and pesticide residue limits in mandarins.

The manner of transferring requirements along the supply chain is a major issue. The survey reveals that the agencies usually pass requirements on to suppliers in written form, e.g. via e-mail (86%), or specify them in the contract (56%), while 17% of respondents receive them in an informal verbal way only. The informal verbal transmission becomes more important for suppliers in turn passing on requirements to their upstream producers. In this case, 40% pass them on verbally, 39% specify them in their contracts with upstream producers and still the majority of 72% communicate them in a written manner.

### 3.4. Business practices and food loss

We surveyed views on the existence and manifestation of potential business practices in general that may be associated with food loss (Fig. 5). Suppliers perceive the Lidl product specifications to be clear, potential adjustments to be well communicated and standards to be generally reliable. The large majority of suppliers moreover states that the retailer provides justifications for return deliveries. 53% of respondents generally comprehend these justifications. According to the suppliers, there is still room for manoeuvre with regards to the flexible handling of product requirements and the timing as well as coherence of advertisement campaigns. The results further highlight a disagreement as to whether short-term call-offs of fruit and vegetable quantities are subject to fluctuations and whether they align well with annual volume planning. The majority states to produce buffer quantities in order to be able to deliver if demanded quantities increase short-notice. For most, but not all of the suppliers, quantities to be delivered are clear no later than 24 hours prior to the actual delivery. Moreover, communication between supply chain actors is regarded as sufficient and alternative marketing of class II as well as class I products is legitimate in most cases.

We also asked participants to assess to which extent business practices contribute to the creation of food loss between primary production and retail. 8% of all respondents indicate that business practices are a food loss driver, while 14% are unsure and the majority does not perceive them as a driver. The participating suppliers perceive natural causes (35% of respondents), product specifications (21% of respondents) and market environment (19% of respondents) as major food loss driver. Only technological drivers (3% of respondents) are perceived as less relevant.

When looking at certain business practices in detail (Fig. 6), again many suppliers do not see a relationship between the practices available for selection and food loss occurrence (green bars). Nonetheless, 15–25% believe that insufficiently synchronised advertisement campaigns, return deliveries, short-notice quantity call-offs and inconsistencies in planning and ordering of volumes by Lidl strongly or very strongly contribute to fruit and vegetables becoming food loss along the upstream supply chain.

Similarly to the product requirements, the extent to which business practices are perceived as contributing to food loss appears to vary by crop. (Table 2). For cucumbers, mandarins, carrots and tomatoes, the suppliers view business practices in general as a stronger food loss driver than for other crops.

### 3.5. Food and non-food channels of substandard produce

From the supplier questionnaire, we calculated a self-assessed average share of 15% of the total production ready for harvest not meeting the Lidl specifications. Fruit and vegetables not fulfilling the requirements do not necessarily end up as food loss. We therefore asked follow-up questions on what happens to these products (Fig. 7). 32% of suppliers indicate not to harvest (farmer suppliers) or purchase (producer associations and brokers) them. This sums up to 3.4% of total production/traded volume that is not harvested/purchased due to the specific quality requirements of Lidl. The remaining percentage of

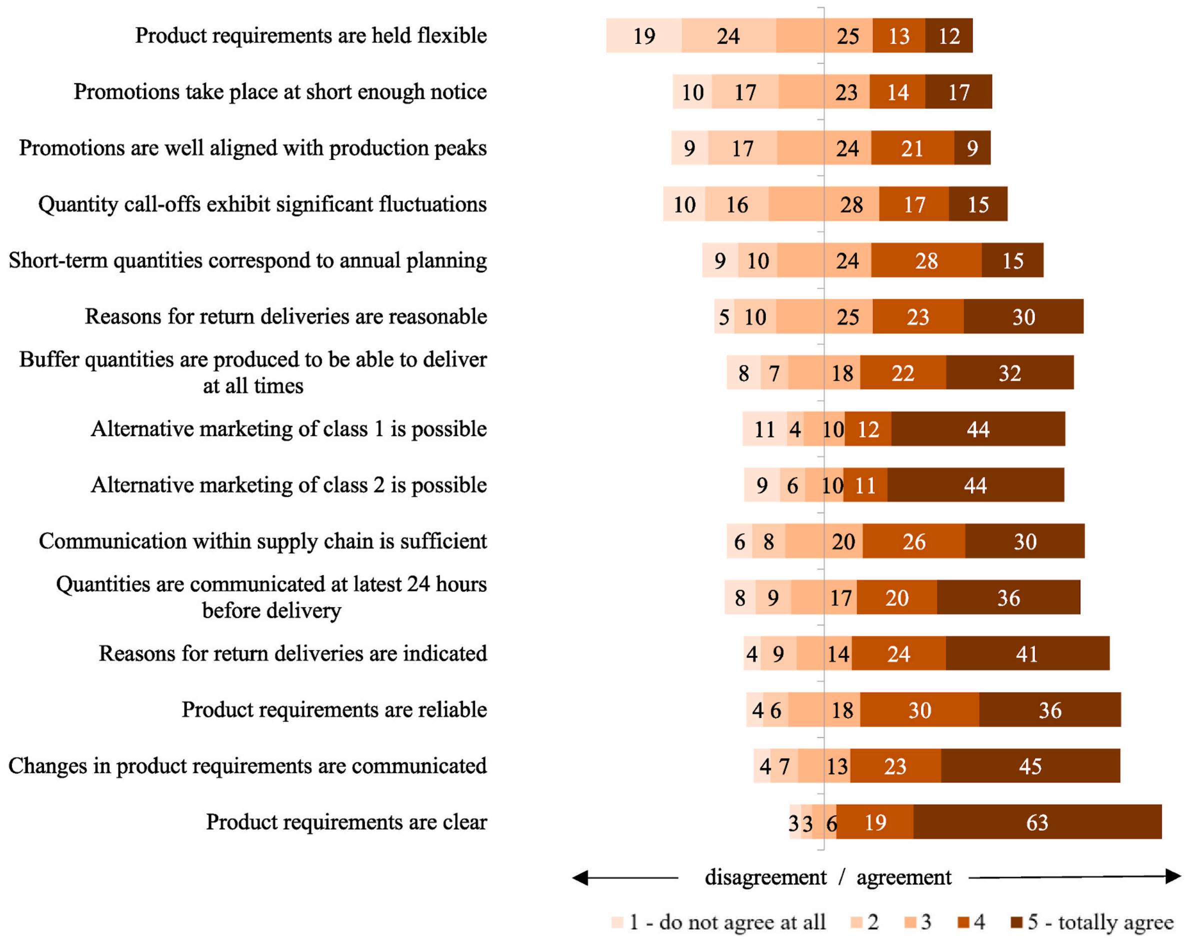


**Fig. 5.** Suppliers' assessment of statements regarding business practices within the supply chain on a Likert scale as percentages of respondents (n = 169; percentages do not sum up to 100% due to omitting NAs).

suppliers nonetheless harvest or purchase the substandard produce or decide on a case-by-case basis whether to harvest/purchase or not. In this case, the fruit and vegetables take other food and non-food channels. Due to the Lidl quality standards, an average of 0.9% of total production/traded volume is being disposed, including biogas, compost and other disposal routes. 1.7% becomes animal feed and only 0.04% is converted into non-food articles. Including the share which is not harvested or purchased, an average amount of 6% of the total production/traded volume or 41% of the substandard produce is lost for human consumption due to the retailer's requirements. The remaining part not complying with the requirements is mainly marketed to wholesalers and other retailers, followed by the food industry. Only a small share is sold via farmer-to-consumer direct marketing.

### 3.6. Factors influencing the amount of substandard produce

We applied Kruskal-Wallis tests and Mann-Whitney-U tests to detect group differences in the following two variables:

A) indicated shares of products not fulfilling requirements,
B) indicated shares of products becoming food loss (disposed, used as animal feed, non-food products or left unharvested),

The categorical variables and their characteristic values representing the groups between which differences are hypothesised are presented in the first column of Table 2. Descriptive statistics of the variables are presented in supplementary material 14.

Both variables (A and B) show significant differences between countries/agencies, via which the produce is traded. The German agency exhibits a significantly higher share of substandard produce compared to the Spanish and the Italian agency. Moreover, its loss share due to product requirements is significantly higher than the one of the Spanish agency. The Kruskal-Wallis test revealed significant differences between crops in the share of products becoming food loss. Namely, the share of substandard produce in carrots is significantly higher than the one of peaches/nectarines and tomatoes. For all other variables, no significant differences were found.

The correlation coefficients calculated for the continuous and discrete variables did not exceed $|0.3|$. Weak negative correlations were found between the total produced or traded volume as well as the share of the crop produced in the open field and the shares of products not fulfilling the requirements. The two mentioned variables also weakly correlate with the share of products becoming food loss.

Table 3 presents the results of quantile regression models for both dependent variables A and B. It can be inferred from model 1 that for the 0.25-quantile (representing the share of the sample that exhibits rather low shares of substandard produce), the share of produce not fulfilling the requirements is significantly lower in Spain as compared to Germany. For the 0.5-quantile, this share is significantly lower in Spain as well as in Italy. Regarding the supplier type, no significant influence was detected. However, the coefficients for producer associations are positive and for brokers negative compared to farmer suppliers in all quantiles.

The 0.75-quantile on the other hand shows significantly lower shares of substandard products for certain crops as compared to the base variable 'apples'. Lower shares can be found in cauliflower, iceberg lettuce,

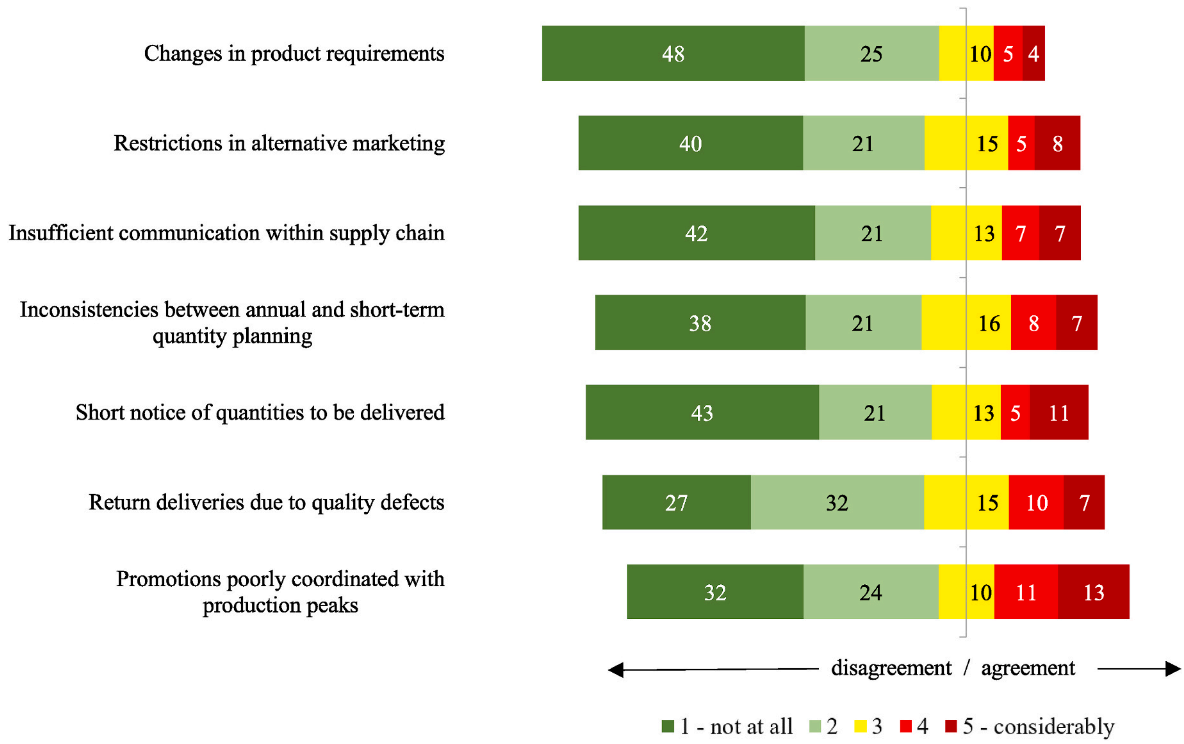


**Fig. 6.** Suppliers' assessment of the extent to which different business practices lead to food loss on a Likert scale as percentages of respondents (n = 149; percentages do not sum up to 100% due to omitting NAs).

carrots, peppers, peaches/nectarines, grapes and, based on a 90% confidence interval, also tomatoes. The total produced/traded volume as an indicator of the supplier size has a significantly positive effect on the share of substandard produce within the 0.75-quantile, although its effect size is small.

In model 2, which estimates the share of products becoming food loss, less influence of explanatory variables was found. With respect to the supplier type, again, the coefficients for producer associations are insignificantly positive and for brokers negative as compared to farmer suppliers in all quantiles. Looking at the crop type, interestingly, the coefficients of the variables 'carrots' and 'peppers' are significantly positive in the 0.75-quantile, although these crops' shares of substandard produce are significantly lower as compared to the base (see model 1).

## 4. Discussion

We interpret our findings by consecutively addressing our four research aims (Section 1), followed by suggesting options for action and discussing the study's limitations.

We addressed the question of how the interplay of a retailing company's product requirements and business practices affects food loss levels in the upstream supply chain of fruit and vegetables. Our findings support previous evidence that retailing companies impose requirements regarding certain characteristics of produce onto suppliers and producers. This in turn leads to sorting out of non-compliant products along the supply chain. Beausang et al. (2017) found that farmers perceive cosmetic specifications as a key cause of food loss. However, companies' product requirements cannot be viewed as strictly established criteria but rather as implicit knowledge. This uncertainty about the very existence, differing perceptions and handling of retailer product requirements, makes the issue of product requirements as a driver of food loss very elusive. We can derive from the suppliers' survey that a combination of product requirements primarily aiming at pesticide residue limits, calibre and other product traits, coupled with a lack of flexibility of these requirements, insufficient timing of promotion periods and inadequate quantity planning increase the risk of food loss within the evaluated Lidl supply chain. Our findings appear to be somewhat transferable: retail fruit and vegetable supply chains in Brazil face similar problems, such as a lack of coordination and information sharing, as well as demand forecasting and control in ordering (Moraes et al., 2022). Devin and Richards (2018), Rakesh and Belavina (2020) and Feedback (2017) describe lacking reliability of requirements and elaborate that retailers neither clearly define standards, nor provide sufficient evidence on the non-compliance of produce in case of a quality-related rejection. Suppliers in our study however describe requirements as rather reliable and are generally aware of the required standards and reasons for rejection, similar to Herzberg et al. (2022). It is not clear whether German retailers are actually more transparent on these issues, or whether this can be explained by the limitations mentioned at the end of this section.

We further aimed at estimating the share of fruit and vegetables not complying with the product requirements set by Lidl. The supplier survey reveals that a mean share of 15% of the total production does not meet the specific standards of the retailer. There is a lack of comparable figures in literature related to grading out of products not fulfilling retailers' specifications. Meyer et al. (2017) report producer estimates of general fruit and vegetable loss between production and store shelf of 20–30%. Baker et al. (2019) conclude that an average of 34% of the marketed volume is left in the field for various reasons in their quantification of fruit and vegetable loss during the production process for California. These estimates, in contrast to the present study, include all kinds of food loss drivers and do not distinguish food loss induced by requirements of the retail sector. Johnson et al. (2018a) show that poor quality (edible as well as non-edible) results in 42% of marketed crop volume being left in the field within their measurements in North Carolina (USA). Porter et al. (2018) estimate that retailers' quality requirements cause food loss rates between 4 and 37% within the European Economic Area. One reason for the low proportion of suboptimal products in Lidl supply chains may be better practices and

**Table 2**
Results of Kruskal-Wallis tests including Dunn-Bonferroni post-hoc tests for categorical variables with more than two characteristic values, Mann-Whitney-U tests for categorical variables with only two characteristic values and Pearson's correlation coefficients for continuous and discrete variables.

| Variables | Share of products not fulfilling requirements (variable A) | | Share of products becoming food loss (variable B) | |
|---|---|---|---|---|
| | Results of Kruskal-Wallis tests | | | |
| | Median | Mean ± SD | Median | Mean ± SD |
| **Country/agency** | p-value = 0.039* | | p-value = 0.009** | |
| DE | 17[a] | 20.9 ± 12.8 | 15[a] | 17.2 ± 113.8 |
| ES | 10[b] | 13.8 ± 17.1 | 5[b] | 8.75 ± 116.6 |
| IT | 10[b] | 15.1 ± 18.4 | 9.5[ab] | 12.6 ± 111.8 |
| **Supplier type** | p-value = 0.338 | | p-value = 0.720 | |
| Farmer supplier | 10 | 15.6 ± 16.4 | 5 | 10.9 ± 13.7 |
| Producer association | 7.5 | 15.5 ± 19.8 | 5 | 11.8 ± 20.4 |
| Broker | 5 | 9.17 ± 8.79 | 10 | 9.64 ± 6.23 |
| **Selected crop** | p-value = 0.329 | | p-value = 0.003* | |
| Apples | 20 | 26.7 ± 26.6 | 1[ab] | 1 |
| Avocados | 10 | 18.2 ± 20.0 | 3[ab] | 3 ± 2.83 |
| Cauliflower | 5 | 8.78 ± 10.3 | 3[ab] | 6.8 ± 8.35 |
| Iceberg lettuce | 10 | 9.25 ± 7.64 | 10[ab] | 8.62 ± 8.08 |
| Strawberries | 5 | 16.3 ± 27.6 | 10[ab] | 38.3 ± 53.5 |
| Cucumbers | 8 | 11.8 ± 13.8 | 8[ab] | 8 ± 9.90 |
| Mandarins | 15 | 19.8 ± 18.1 | 5[ab] | 8.44 ± 8.80 |
| Carrots | 20 | 20.0 ± 13.5 | 20[a] | 24.5 ± 14.4 |
| Peppers | 10 | 10.7 ± 11.4 | 3[ab] | 7 ± 7.42 |
| Peaches/Nectarines | 5 | 13.1 ± 17.3 | 1[b] | 1.4 ± 2.07 |
| Tomatoes | 7.5 | 16.2 ± 20.5 | 5[b] | 5.33 ± 5.98 |
| Grapes | 4.5 | 7.5 ± 8.54 | 4[ab] | 3.67 ± 1.53 |
| | **Results of Mann-Whitney U-Tests** | | | |
| | **Median** | **Mean ± SD** | **Median** | **Mean ± SD** |
| **Exclusively supplying this retailer** | p-value = 0.095. | | p-value = 0.224 | |
| Yes | 12.5 | 18.7 ± 20.4 | 10 | 17.6 ± 24.6 |
| No | 10 | 13.9 ± 16.3 | 5 | 8.86 ± 10.5 |
| **Organic produce** | p-value = 0.783 | | p-value = 0.723 | |
| Yes | 10 | 13.7 ± 14.2 | 5 | 10.8 ± 12.2 |
| No | 10 | 15.1 ± 18.2 | 5 | 11.1 ± 16.8 |
| | **Pearson correlation coefficients** | | | |
| Total produced or traded volume [t/year] | −0.113 | | −0.154 | |
| Number of buyers apart from this retailer | 0.048 | | −0.06 | |
| Duration of the business relationship [years] | 0.049 | | 0.088 | |

Note: SD = Standard deviation; Kruskal-Wallis test and Mann-Whitney-U test were applied to test H0: There are no differences between groups; **.** indicates p-value <0.1; * indicates p-value <0.05; ** indicates p-value <0.001; values with the same accompanying letter are not significantly different at the 10 %-significance level according to Dunn-Bonferroni test. For Pearson's correlation no p-values are reported due to not normally distributed variables.

handling of product specifications. However, this cannot be unequivocally inferred as other influencing factors might be the more precise method of direct field measurement in other studies, natural variations in food loss amounts as well as the consideration of different parts of the supply chain and different food loss fractions and drivers.

Only few previous studies address the question of what happens to produce not complying with retailer requirements. In our study, a share of 6% is not used for human consumption due to the non-compliance. This part is predominantly not being harvested or purchased by the suppliers, used as animal feed or being disposed. Hartikainen et al. (2018) estimate this proportion of so-called side-flow between 1 and 26% for vegetables and 10 and 14% for fruits. However, they did not narrow their scope to food loss induced by retailers' specifications. For the remaining substandard produce, in this study most frequently utilised channels are wholesale, other retailers and the processing industry. In line with Delgado et al. (2021), Fernandez-Zamudio et al. (2020) and Baker et al. (2019), leaving non-conforming products in the field during the harvesting process is a common strategy. It does not make economic sense to harvest produce unlikely to be sold for a reasonable price afterwards. What happens to substandard products also depends on the potential marketing channels at hand. For instance, in our sample some products can be processed more easily than others. Furthermore, farmer suppliers are more likely to be able to use produce as animal feed due to their network and some products can be marketed to other supermarkets as the respective requirements may differ. It also influences the further path of the products, at which point in the supply chain grading processes and quality controls take place. Meyer et al. (2017) make similar observations and state that hand-picked crops, such as salad, cauliflower and broccoli, are out-graded during harvesting while for crops like apples, potatoes, carrots and onions, alternative food use is more likely due to later grading.

We ultimately aimed at answering the question whether the alignment with the retailer-requirements is harder to achieve for certain crops, product specifications and suppliers than for others. The statistics revealed that some crops, such as cauliflower, iceberg lettuce, carrots, peppers, peaches/nectarines, grapes and tomatoes are less likely to fail meeting the requirements. Interestingly, loss rates due to the retailer's standards in carrots and bell peppers in our study are nonetheless significantly higher. This might be due to restricted alternative processing options and the higher chance of carrots becoming animal feed. This shows that the further path of substandard products depends on the crop and underscores the relevance of diverse distribution channels for food loss prevention (Chaboud and Moustier, 2021). As opposed, Baker et al. (2019) found rather low loss rates for tomatoes but high loss rates for salads and cabbages, which might be due to the broader focus on food loss drivers apart from quality standards. There are also requirements that seem to be harder to reach, such as pesticide residue limits, calibre but also shape and curvature. The relevance of pesticide

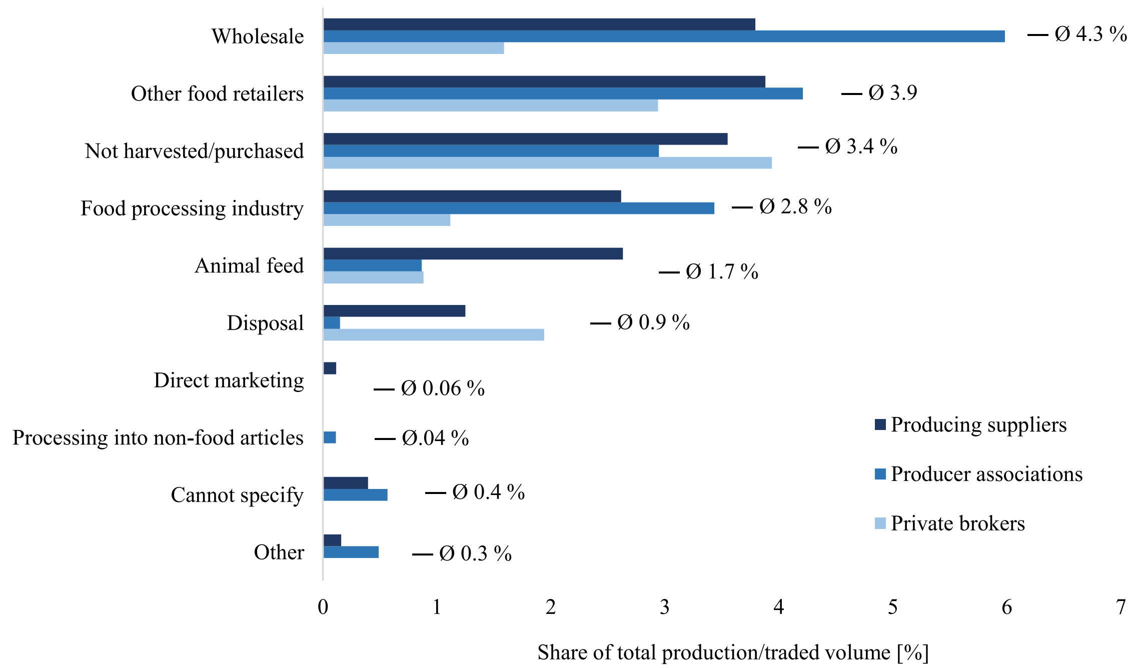


**Fig. 7.** Trade and utilisation channels for products that do not meet the retailer's requirements (as a percentage of total production for farmer suppliers and of traded volume for producer associations and private brokers, n = 139).

**Table 3**
Results of quantile regression models for dependent variables A and B for 0.25, 0.5 and 0.75 quantiles.

| Variables | Model 1 with dependent variable A: Share of products not fulfilling requirements | | | Model 2 with dependent variable B: Share of products becoming food loss | | |
|---|---|---|---|---|---|---|
| | Regression results per quantile | | | Regression results per quantile | | |
| | q25 | q50 | q75 | q25 | q50 | q75 |
| **Country/agency** | | | | | | |
| DE | base | base | base | base | base | base |
| ES | −9.40* | −12.44* | −11.58 | −0.05 | −4.00 | −9.56 |
| IT | −6.93 | −11.19* | −11.07 | 2.30 | 2.81 | 0.52 |
| **Supplier type** | | | | | | |
| Farmer supplier | base | base | base | base | base | base |
| Producer association | 0.94 | 2.76 | 0.12 | 2.05 | 2.22 | 1.10 |
| Broker | −1.68 | −2.30 | −4.43 | −5.17 | −9.24 | −7.83 |
| **Selected crop** | | | | | | |
| Apples | base | base | base | base | base | base |
| Avocados | 3.46 | −5.70 | −27.29 | 6.03 | 10.73 | 13.92 |
| Cauliflower | −3.73 | −19.33 | −54.07** | 3.18 | 8.75 | 13.47 |
| Iceberg lettuce | −2.15 | −14.02 | −48.44** | 7.24 | 15.80 | 20.57 |
| Strawberries | −2.62 | −16.39 | −34.15 | 8.00 | 17.49 | 111.82 |
| Cucumbers | −3.37 | −1.14 | −26.75 | 5.29 | 8.51 | 25.90 |
| Mandarins | −2.19 | −1.58 | −18.64 | 6.30 | 14.56 | 21.82 |
| Carrots | 4.78 | −1.95 | −37.39* | 22.29 | 30.68 | 35.49* |
| Peppers | −1.84 | −9.81 | −38.71* | 7.04 | 12.81 | 32.54. |
| Peaches/Nectarines | −1.96 | −11.97 | −37.63* | 1.71 | 10.46 | 15.15 |
| Tomatoes | - 2.40 | −6.05 | −29.01. | 6.94 | 11.96 | 18.82 |
| Grapes | −3.93 | −13.65 | −45.42** | 6.55 | 14.26 | 15.95 |
| **Organic produce** | | | | | | |
| Yes | base | base | base | base | base | base |
| No | 2.18 | 1.22 | 0.26 | 0.74 | 1.51 | 2.38 |
| Total produced or traded volume [t/year] | < −0.01 | < −0.01 | < −0.01* | < −0.01 | < −0.01 | < −0.01 |
| Number of buyers apart from this retailer | 0.10 | 0.82 | −0.35 | 0.30 | 0.07 | 0.13 |

Note: . indicates p-value <0.1; * indicates p-value <0.05; ** indicates p-value < 0.001.

residue requirements of retailers as a food loss driver is, compared to cosmetic requirements, taken into account by only few scholars, e.g. by Ludwig-Ohm et al. (2019) and Meyer et al. (2017). Our study shows that this topic should be given a much higher priority. With respect to the suppliers' characteristics, we were able to show that German suppliers exhibit a significantly higher share of substandard products. This is likely due to them producing a large amount of carrots and due to the high percentage of farmers in this sub-sample.

It has been found that many retailing companies in different countries set product specifications for distinct fruits and vegetables (Devin and Richards, 2018; Meyer et al., 2017; Porter et al., 2018; Willersinn et al., 2015). Although the exact specifications differ between retailing chains (Baker et al., 2019; Herzberg et al., 2022), we are able to draw general suggestions for retailers regarding the adjustment of certain product specifications and business practices from the results. Retailers should check whether they can handle product requirements less strictly, in particular when it comes to pesticide residue limits and calibre. With business cases such as 'Bio-Helden' (organic heroes) and 'Die krummen Dinger' (the crooked things) some retailers located in Germany have already proven that marketing of selected substandard fruits and vegetables can work (Aldi Süd, 2023; Kaufland, 2023; Rewe Group, 2023). It has been shown that there is scope to market suboptimal products, especially when deviations in shape and size are moderate (Loebnitz et al., 2015). Potential strategies include reducing prices (Aschemann-Witzel et al., 2020), mixing suboptimal and optimal foods and highlighting their naturalness and authenticity (Qi et al., 2022), or appealing to consumers' value orientation, commitment to environmental sustainability, and perceived environmental effectiveness (de Hooge et al., 2017). Retailers, especially in the organic segment, may have untapped potential to sell suboptimal products and may even lose opportunities to improve their image by missing out on selling these products (Louis and Lombart, 2018). Of course, which standards to liberalise must be chosen with sound judgement so as not to induce an increase in food loss and waste at processing, storage, retail and consumption stages (Soma et al., 2021; Willersinn et al., 2015). As suppliers, contrarily to company representatives, perceive product specifications as rigid, it seems that potentially existing flexibility and tolerance must be communicated better along the supply chain. Additionally, promotion campaigns should be synchronised more with production peaks to enable a more reliable planning of quantities and yearly consultations should be aligned better with short-term calls of quantities. By setting ambitious pesticide residue limits, retailers aim to meet societal demands for health, environmental conservation and sustainability and avoid negative publicity. However, retailers must consider arising trade-offs between pesticide residue reduction and food loss reduction (for sustainability trade-offs and food waste reduction see Latka et al. (2022)). Similar to Chaboud and Moustier (2021), this study underlines the importance of diverse marketing channels and networks for food loss reduction. Therefore, retailers should maintain already existing marketing networks and actively support access to further alternative marketing and processing channels for their suppliers. They should also ensure that corporate packaging design and early packing do not hinder taking advantage of these channels. Actively promoting alternative marketing also implies taking responsibility, and potentially even ownership, of the produce earlier in the supply chain (Devin and Richards, 2018). Ownership would create economic incentives for retailers to reduce food loss. In this way, retailers would not only benefit from improved supply chain governance, but would also have to bear the cost of food lost in the early stages of the supply chain.

There are limitations within the study design and implementation that are likely to influence our results. An underestimation of food loss quantities is likely as our data is based on supplier estimates. Baker et al. (2019) showed for California, that direct measurement of loss on the field is 157% (median) higher than growers' estimation. Two studies conducted in North Carolina (USA) show that on-field measurement results in considerably higher field-loss figures than estimates by involved experts, such as farmers (Johnson et al., 2018a,b). In addition, the potentially highly relevant loss point of upstream primary producers is not incorporated in this paper. Moreover, sample sizes for some crops are rather low and we cannot appraise the representativeness of the sample due to missing information on the population characteristics. The involvement of Lidl was administratively helpful, but a potential biasing effect, for example due to sending out of the questionnaires by the agencies, cannot be precluded. The potential for bias due to a lack of confidence in the anonymity of the survey as promised to respondents must also be taken into account.

## 5. Conclusions

The conducted case study with the German based retailing company Lidl underpins that retailer-specific product specifications and business practices represent drivers of food loss within their supply chain. Suppliers regard product requirements as the second most important reason for food loss, after natural causes. They state that 15% of the produce grown or traded does not meet the retailer's requirements. Although a large fraction of this produce is marketed elsewhere, 6% of fruit and vegetables in the Lidl supply chain becomes food loss due to sorting out according to its specific product requirements. These percentages are comparably low due to the narrow focus on retailers' specifications as food loss driver, the focus on suppliers rather than producers, potential underreporting and further methodological limitations within this paper.

Diverging from previous findings that highlight traits like shape and colouring as problematic, in our case calibre requirements (mass and size) as well as pesticide residue limits most frequently lead to food loss. In order to reduce food loss levels in the upstream supply chain, retailers should reconsider the level of strictness and rigidity of their own requirements, prioritise potential trade-offs between food loss and pesticide residue requirements, better coordinate promotional campaigns and adjust ordering processes. They should moreover take responsibility for the produce earlier in the supply chain and therefore actively promote alternative marketing and processing channels for suboptimal produce and minimise rejection practices.

All in all, it seems that a differentiated view on product specifications and business practices is required. This view should consider that different specifications and practices affect certain crops and supply chains more than others. However, in our study we could only statistically verify this statement for the sourcing country and for some crop types. Future research should be based on larger sample sizes and be complemented by on-site quantification. A further basic requirement for understanding and tracking food loss that occurs due to retailers' product requirements is to consider pre-harvest and harvest losses. Moreover, future research should replicate similar studies with other retailing companies and for further countries, crops and supply chains to learn more about the reasons why some suppliers perceive specifications and practices as food loss drivers and still many do not. Finally, the effect of potential implementations of the recommendations developed in this paper should be scientifically monitored.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

## Acknowledgements

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.137940.

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